# A PRECISION LAUNCH TECHNIQUE FOR INSENSITIVE MUNITIONS FRAGMENT IMPACT TESTING

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*A precision launch system for conducting Fragment Impact testing as defined in MIL-STD-2105B was designed and developed at the University of Denver, Denver Research Institute (DRI) as an alternative to the FRAGMAT explosive launcher. DRI and National Technical Systems (NTS) are collaborating to use this precision system to conduct Fragment Impact tests against component and All-Up-Round (AUR) munitions at NTS's Arkansas test facility. This specialized launch system has the ability to precisely target and impact shielded and highly sensitive S&A and fuzing train components to enhance reliable determination of reaction origins. The technique utilizes high velocity 40 mm powder guns to deliver two 0.5-inch (12.7 mm) cubical fragments at 8300 $\pm$ 300 ft/s (2530 $\pm$ 91 m/s). The primary advantages of this system as compared to the FRAGMAT explosive launcher are, (1) drastically improved impact control and consistency and (2), reduced parasitic overpressure and test area damage which often obscures and confuses test article reaction.*

## 1.0 INTRODUCTION

The most problematic of the MIL-STD-2105B Insensitive Munitions (IM) test protocols is the Fragment Impact test. Achieving both test performance requirements <u>and</u> accurate reaction evaluation can be difficult. The 8300 ft/s (2530 m/s) impact velocity requirement dictated the design and customary use of high-energy explosive launch devices, which influence and corrupt the measurement of test parameters while often obscuring the test article reaction. These undesirable parasitic influences result in highly subjective, low-confidence evaluations and potentially inaccurate safety qualifications of munitions.

## 1.1 MIL-STD-2105B FRAGMENT IMPACT TESTING

There are multiple Fragment Impact test requirements prescribed in MIL-STD-2105B. The standard explicitly defines preferred and first alternate methods with regard to fragment type, velocity and number of fragment impacts.[1] Section 5.2.4.2 specifies the preferred test as requiring *"…0.5-inch mild-steel cubes…(with) an impact of at least 2 but not more than 5 fragments…."* [2] These fragments must have a <u>minimum</u> impact velocity of 8000 ft/s (2438 m/s) and a <u>maximum</u> impact velocity of 8600 ft/s (2621 m/s).

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The first alternate test method (Section 5.2.4.2.1) requires a single conical-nosed mild-steel fragment impact at a much lower velocity, 6000 ± 200 ft/s (1829 ± 61 m/s). The article reaction criteria for passing both tests is *"No reaction more severe than Type V…"*, with Type V defined as a burning reaction (Section 3.11).[3] The second alternate test method is undefined with respect to fragment type and article response, permitting customization of the test for special conditions and tactical situations. The passing criteria for the second alternate test is meant to be defined by the test article's specific Threat Hazard Assessment (THA).

This paper focuses on the traditional method of conducting the preferred high velocity multi-fragment test using an explosive launcher, and the Denver Research Institute's development of an alternative precision launch system. This newly qualified alternative delivery technique reduces many of the problems inherent with using explosive launchers, that is greatly improving impact accuracy and reducing extraneous test effects, thus leading to increased confidence in munition reaction evaluations.

## 1.2 LAUNCH TECHNIQUES

### 1.2.1 <u>FRAGMAT Launcher</u>

The preferred method's multi-fragment launch requirement has traditionally been met using the Naval Air Warfare Center (NAWC) developed fragment projector, also known as the FRAGMAT launcher. The original 25 fragment explosive launcher was developed for use in the Multiple Fragment Impact Test (FRAGMAT).[4] The FRAGMAT launcher explosively accelerates several cubical fragments, usually in groups of 5 to 25, producing fairly random impact dispersion and fragment orientation. This paper discusses general FRAGMAT launcher characteristics as background for describing alternative methods. The reader is referred to the References for further detail and history about the design and development of the FRAGMAT launcher,

The current NAWC five-fragment launcher consists of relatively simple components, made from inexpensive and readily available materials. The main elements of this launcher are:[5]

1. Fragments – Five 0.5 x 0.5 x 0.5-inch (12.7 x 12.7 x 12.7 mm) mild-steel cubes with a nominal weight of 250 grains each;
2. FRAGMAT Projector – a 4-piece, 5-degree angled and spot-welded steel frame with five cubical fragments inset into the interior opening of the frame;
3. Projector Box – a wooden rectangular box with inside dimensions of 8.0 x 8.0-inches (20.32 x 20.32 cm), constructed of 0.75-inch (1.90 cm) thick plywood. The box is used as the explosive mold.
4. Explosive Fill –Composition B Grade A melt-cast explosive using a water-heated riser to control shrinkage;
5. Aft End Piece – 0.75-inch (1.90 cm) thick wooden plate with five access holes to accept Composition C4 booster pellets;
6. Forward End Piece – 0.75-inch (1.90-cm) thick wooden plate with center cutout to accept the outside dimensions of the FRAGMAT.

Figure 1 illustrates the typical FRAGMAT assembly for the 5-fragment configuration. Assembly of the 4-piece projector is accomplished using ordinary nails, bolts, RTV sealant, epoxy resins, and cyanoacylate adhesives.

The length of the explosive fill/box determines fragment velocity. Approximate charge length and corresponding fragment velocity has been extrapolated from test data collected by NAWC for the Composition B projector design.[6] These data are shown in Table 1.0. Of particular note is the large amount of explosive material needed to provide the preferred MIL-STD-2105B fragment velocity of 8300 ± 300 ft/s (2530 ± 91 m/s).

**Table 1. NAWC Five Cube FRAGMAT Projector Characteristics**

| EXPLOSIVE LENGTH (in) | EXPLOSIVE WEIGHT (lb) | DESIRED VELOCITY ft/s |
|---|---|---|
| 9.02 | 34.43 | 6,000 |
| 9.36 | 35.69 | 6,500 |
| 9.69 | 36.96 | 7,000 |
| 10.02 | 38.24 | 7,500 |
| 10.35 | 39.50 | 8,000 |
| 10.55 | 40.26 | 8,300 |
| 10.68 | 40.77 | 8,500 |
| 11.02 | 42.04 | 9,000 |
| 11.35 | 43.31 | 9,500 |
| 11.68 | 44.58 | 10,000 |

### 1.2.2 Launcher Variations and Experience

National Technical Systems (NTS) has successfully used a variant of the five fragment launcher[7] at its facility in Camden, Arkansas to perform MIL-STD-2105B Fragment Impact tests against several munitions. NTS modified the design of the NAWC FRAGMAT launcher before using it for the first time. The explosive fill was changed from Composition B to a 70/30 Octol because of greater local availability and to simplify the melt-cast process – providing a higher confidence in the quality of the final casting. The NTS FRAGMAT castings with Octol explosive were produced using standard sedimentation casting processes and produced an estimated loading density of 1.80 g/cc or greater.[8]

NTS ran several calibration tests using the modified fragment projector. After four calibration tests using the five fragment projector, the modified launcher provided a mean velocity of 8258 ft/s (2517 m/s) and an average of three fragment impacts within an 11.0 x 8.0-inch (27.9 x 20.3 cm) area at a stand-off of 18.0-feet (5.48 m). The final charge sizing was 8.0 x 8.0 x 12.25-inches (20.3 x 20.3 x 31.11 cm) long with an explosive weight of approximately 51.0 pounds (23.1 kg), a 27% increase over the NAWC design. This extreme amount of explosive presented fixture and set-up problems, particularly shielding of the test article and instrumentation as well as parasitic influences upon the pressure-time measurements and high-speed film records used to evaluate reaction response.

The net explosive weight of the FRAGMAT launcher is often greater than the net explosive weight of the munition. Interpretation of the pressure-time traces can thus be difficult, especially when the reaction of the test article coincides with or is obscured by the pressure-wave generated by the launcher. Additionally, the large fireball and smoke cloud produced by the launcher obscures viewing of the article and its early time reaction(s).

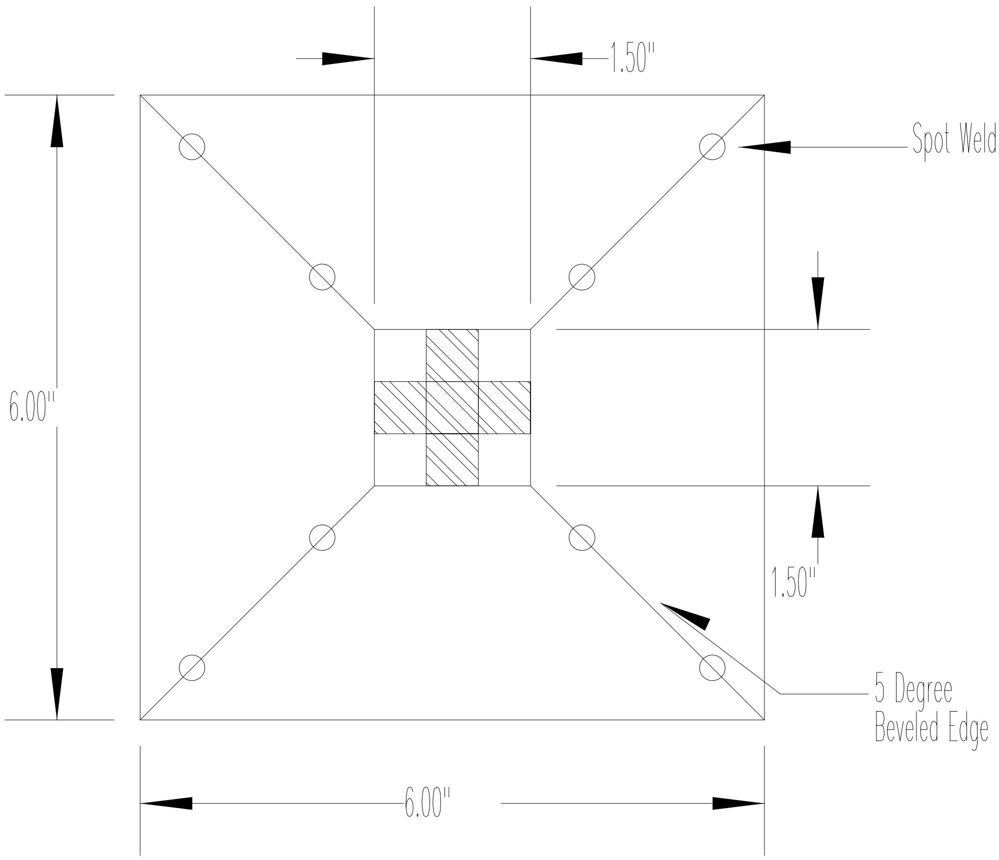


**Figure 1. 5 Fragment FRAGMAT Projector Assembly**

Another difficult problem is shielding the test article from the FRAGMAT launcher. The heavy FRAGMAT projector plates (four pieces), unless stripped from the shotline by a heavy shield, may impact the test article introducing unwanted stimuli. Calibration tests with the NTS modified FRAGMAT launcher resulted in the projector plates penetrating the original shield, a 2.0-inch (5.08 cm) thick RHA plate, producing large spall debris that would have impacted the AUR test article. Two of the five cubical fragments impacted upon this shield, at its standoff distance of 9.0-feet (2.74 m). Additional RHA shielding, increased to 4.0-inches (10.16 cm) thick, was needed to overcome this spalling problem.

While the FRAGMAT launcher is frequently used to perform the MIL-STD-2105B Fragment Impact test to specification, a cleaner, more precise delivery technique is highly desirable. Particularly important is the ability to precisely control the impact location and number of fragments delivered to the target while reducing the damaging and disruptive influences of the excessive explosive materials in the FRAGMAT.

Accomplishing these goals permits the test to be much more precise, repeatable, and far less subjective in evaluation of test article reaction. The DRI gun-launched system of fragment delivery meets these goals.

## 2.0 PRECISION DELIVERY OF FRAGMENTS

The inability of the explosive launcher to deliver fragments accurately and consistently complicates the ability to test munitions for sensitivity. The most sensitive part of a munition frequently is the initiation train and its associated components.

Fuzes, detonators, and booster pellets are typically made from more sensitive energetic materials and are by design as small as possible. In addition, they are often well shielded by external components, such as the casing, liners, and bulk energetic materials.

Placement of the initiation train frequently occurs away from the main portion (largest presented area) of the munition. MIL-STD-2105B recognizes this occurrence and its implications for safety, requiring two impacts against separate test articles -- both the munitions' main charge and its more sensitive components.[9]

Accurately impacting these smaller targets/areas is difficult with a FRAGMAT device as previously discussed. For these reasons, DRI designed and developed an alternative ballistic launch method for delivering fragments to small targets with precise impacts and fragment orientations. Previous experience with high-velocity powder guns and sabot-launched cubical fragments provided the baseline technology for developing a twin powder gun launch system for precisely and consistently conducting the preferred Fragment Impact test.

## 2.1 ORIGIN OF THE PRECISION DELIVERY TECHNIQUE

The concept for precisely delivering two 0.5-inch (12.7 mm) cubical fragments to a relatively small target using a powder gun originated from DRI's use of intermediate caliber, long length powder guns to fire various composition, shape, and size fragments. These fragments were launched over a large range of velocities, 1000 - 8000 ft/s (305 - 2438 m/s), to perform penetration mechanics research against aircraft materials. The use of a high-velocity powder gun for delivering cubical fragments was proven during this research – the challenge was to deliver two fragments, at consistently high velocities, and at precise impact locations.

## 2.2 APPLICATION TO MIL-STD-2105B REQUIREMENT

There are essentially three main test criteria that must be achieved to successfully conduct the MIL-STD-2105B Fragment Impact test. These are (1), multiple fragment impacts (2), an impact velocity above 8000 ft/s (2438 m/s) and (3), precise impact location – either on the main charge or on the "*…most shock-sensitive location…*" of the munition.[10]

While impact location is not explicitly stated as test criteria, it is clear that in order to adequately and confidently test the smaller sensitive components within a munition that an accurate impact is of great importance. This is particularly true for smaller munitions and munition components, which by their size and geometry offer reduced presented area and minimal impact targets, even in their main charge sections.

In 1989, DRI was tasked to conduct Fragment Impact tests to MIL-STD-2105A against several types of 2.75-inch Rocket Warheads for the U.S. Navy. Both the main energetic material charges and the more sensitive initiation train components of the warheads were specified as impact locations.

Discussions with Navy technical personnel concerning the difficulty of reliably impacting these small targets with the FRAGMAT launcher led to DRI proposing modification of an existing 40 mm powder gun design into a twin barrel system that would be capable of impacting targets within ± two fragment calibers, approximately 2.0-inches (5.08 cm) in diameter.

Based upon the test criteria described above and the large number of tests needed it was determined that implementing a dual gun system to fully satisfy these demands was appropriate. The design of the system required completion of these major tasks:

1. Design of matching 40 mm rifled barrels with a length of 12.0-feet (3.7 m);
2. Design and fabrication of individual barrel mounts such that convergence of shotlines occurred at a minimal distance – at 30.0 to 40.0-feet (9.14-12.19 m);
3. Fabrication of a hardened, movable shelter for the mounts and gun system as protection from potential munition blast and fragmentation damage;
4. Development of a dual firing system capable of simultaneous and time-delayed initiation.

## 2.3 HISTORY AND USE OF HIGH-VELOCITY POWDER GUNS AT DRI

A variety of calibers, lengths, rifled and smooth bore powder guns were utilized at DRI throughout the 1980's to produce highly accurate impacts of spheres, cubes, cylinders, rods and Fragment Simulating Projectiles (FSP). These powder guns were fired using variable main charges in different volumetric "breech chambers" using conventional sporting propellants such as the IMR series of rifle and handgun powders. In nearly every instance the fragments were launched in a sub-caliber condition, using multiple-piece interlocking sabot designs. Typical of these launch systems were 25 and 40 mm diameter test barrels, both rifled and smooth, in lengths ranging from 10.0-foot to 13.0-foot (3.05 - 3.96 m).

By the end of the decade, a 40 mm rifled tube in a nominal 12.0-foot length (3.66 m) became the DRI standard for fragment launching, particularly cubical fragments. This system consistently launched a 0.5-inch (12.7-mm) 240-grain steel cube at velocities in excess of 8000 ft/s (2438 m/s), with impact accuracy of one fragment caliber at a range of approximately 10.0-feet (3.05 m). In addition, cube orientation at impact (integrated pitch and yaw) was typically ± 3 degrees when launched "flat" (surface-face normal to target).

# 3.0 PRECISION DELIVERY SYSTEM DESCRIPTION

## 3.1 HARDWARE

The original ballistic delivery system developed by DRI consisted of the following main components. Figure 2 illustrates the breech blocks and original barrels installed in their mounts within a hardened protective structure.

1. Two 40 mm rifled bore test barrels with 3.0-inch (7.62 cm) diameter by 13-foot long (3.96 m);
2. Two steel charge blocks with pressure ports that individually thread onto each barrel;
3. Two steel block inserts to seal the powder chambers and permit primer charge access;
4. Two steel primer inserts that hold a small propellant priming charge and M51A2 electric primer;
5. Two steel cap blocks with expendable firing pin for circuit completion and firing of the primers;
6. One variable delay (0-1 second) firing set for delivering parallel high-voltage pulses to "matched" electric primers (checked and matched by resistive values);
7. Six channel make-circuit power supply and signal box;
8. One fixed table mount with steel clamping blocks;
9. One traversing and elevating mount with steel clamping blocks;
10. Modified 7-foot (2.13 m) diameter by 12-foot (3.66 m) long by 0.75-inch (1.91-cm) thick steel storage tank for protection.

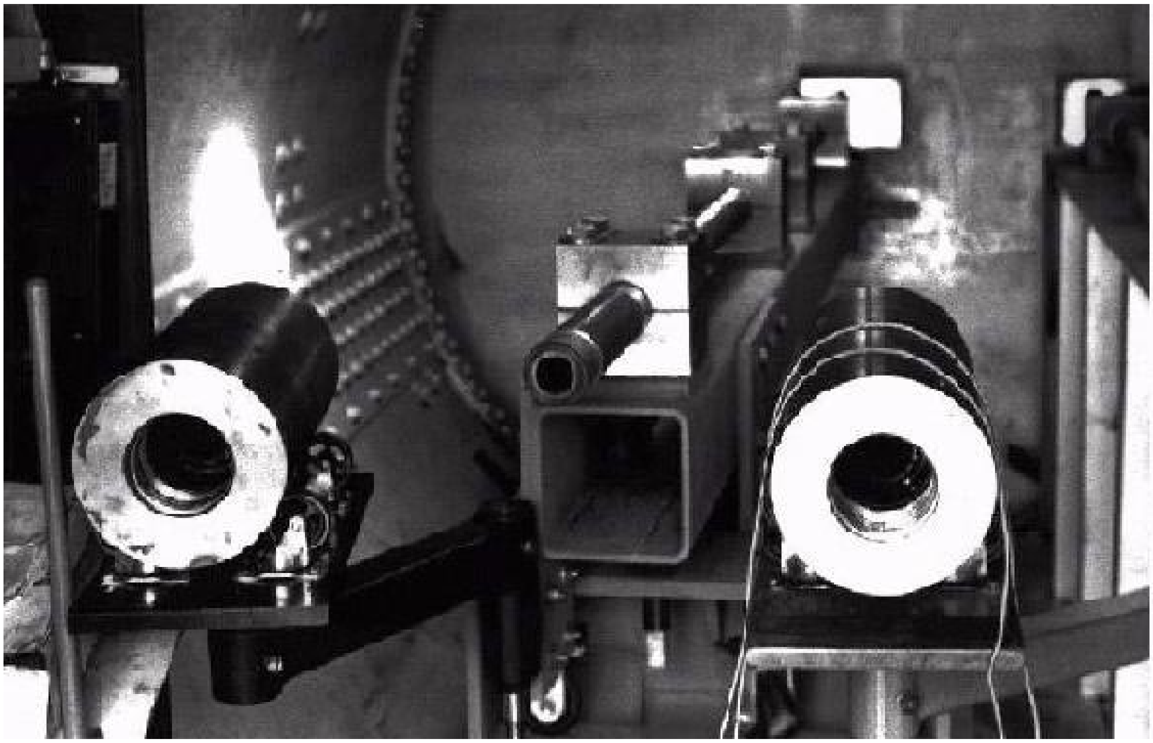

**Figure 2. Original 40 mm Mann Barrels and Powder Blocks**

## 3.2 LAUNCH PACKAGE

### 3.2.1 Sabots

The 240-grain cubical fragments are sub-caliber launched in the 40-mm test barrel using six-piece interlocking sabots. The sabot sections are manufactured from varying percentages of glass-fiber reinforced polycarbonate. The polycarbonate material is injection molded under elevated temperature and pressure to minimize internal void formation. Each individual sabot section is separately molded to produce a “blank” part, greatly reducing mold size, cross-sectional thickness, and cost per unit. The solid near-net sized, cylindrical sabot is assembled from six individual sections using ordinary household adhesives.

The sabots are then machined to precise dimensional tolerances, typically ± 0.001-inch (0.0254 mm), depending upon actual breech section diameter in the test barrel. This practice maximizes shot-to-shot consistency in sabot-to-barrel friction and inertial, i.e. “sticking”, forces.

The fragment cavity is custom machined for each shot according to fragment shape and length, with a nominal 45-degree taper machined into the leading end of the sabot. This sabot design yields extremely consistent fragment/sabot separation, trajectory, and impact orientation as evidenced in Figure 3, a set of orthogonal radiographs depicting pre- and post impact of a 0.5 x 0.5-inch (12.7 x 12.7 mm) cubical fragment launched from a 40 mm rifled test barrel.

### 3.2.2 Obtuator

Depending upon the overall size and length of the sabot and fragment assembly, single or multi-piece polyethylene obtuator discs are used in addition to the main sabot. These discs provide additional setback support for the fragment/projectile as well as provide a gas-seal. Gas sealing, particularly at the high-velocity range of the Fragment Impact test is desirable to minimize in-bore blow-by around the launch package, greatly enhancing the performance and consistency of in-bore pressure and muzzle velocity.

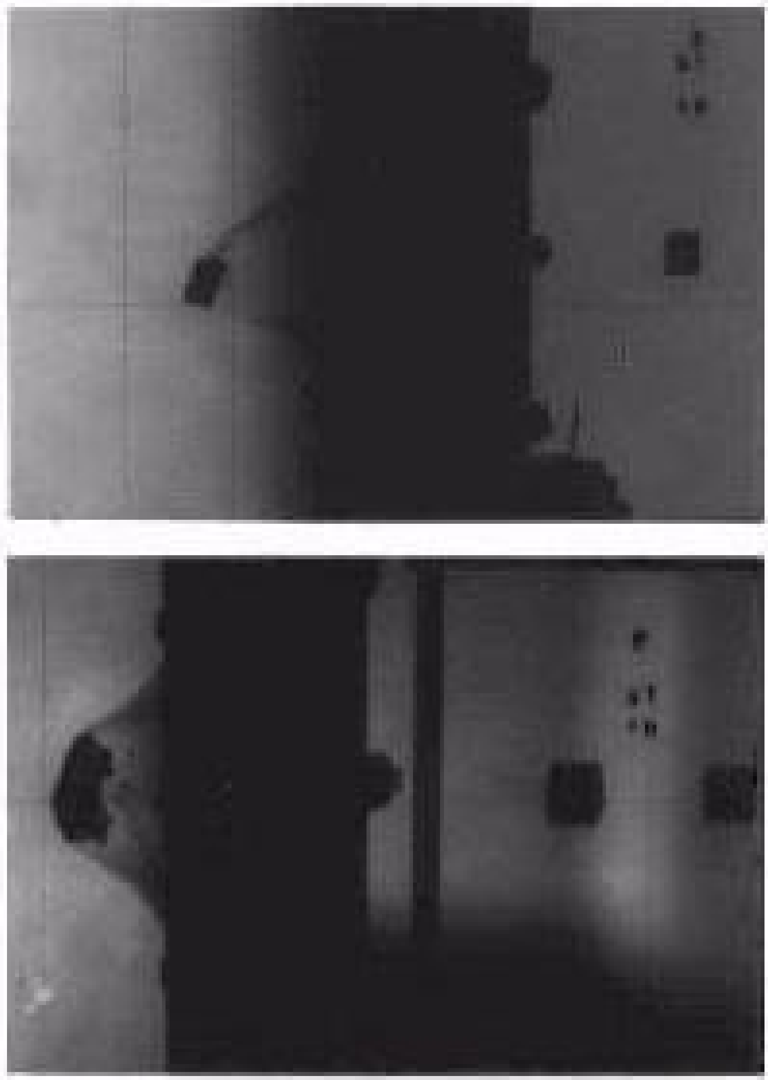

**Figure 3. Cubical Fragment Launched from 40 mm Barrel**

## 3.3 INSTRUMENTATION

Fragment velocities are measured using traditional make-circuit screens comprised of three layers of 1 mil aluminum foil separated by thin insulating paper. These simple screens are part of an "open" electrical circuit. Impacting the screens with a fragment completes the circuit, generating a conditioned 75-volt signal, providing an accurate screen-to-screen time. Both gunlines are instrumented with multiple make-screens to provide redundant velocities for each fragment.

Test events are controlled and recorded using a custom DRI Data Acquisition and Analysis System (DAAS). This system includes a programmable controlling sequencer that manages all timing, firing and high-speed digital recording of test signals. The digitizing modules (LeCroy 6810's) and custom signal conditioning are used to record various test events, including velocity screen signals and blast pressure with standard sampling rates of one microsecond over a range of 128,000 samples. The DAAS system is also configured to provide calibration step pulses and monitor a portion of the pre-event time range for each channel used.

Calibration shots are fired using single and dual guns to establish muzzle blast magnitude and timing at the blast pressure gauges used for measuring article reaction. These measurements are critical for post-test analysis and comparison in identifying and measuring test item reaction.

## 4.0 PERFORMANCE HISTORY

### 4.1 DRI PROGRAMS

Over 100 successful firings for record were conducted at DRI's test facilities in Denver, Colorado from 1990 through 1995. Some of the programs that utilized the precision delivery system during that time include:

1. M151 Warhead With M427 Fuze;
2. M427 Point Detonating Fuze With Inert Warhead;
3. MK 352 Mod 2 Point Detonating Fuze With Inert Warhead;
4. M257 Illuminating Warhead With M442 Fuze;
5. WDU-4a/A Flechette Warhead With 113A Integral Fuze;
6. MK 67 Mod 1 Smoke Warhead With MK 352 Mod 2 Fuze;
7. M429 Proximity Fuze With Dummy Warhead;
8. M261 Submunition Warhead With M439 Fuze;
9. M433 Remote Set Fuze With Dummy Warhead;
10. Raufoss Ra-79 Anti-Ship Warhead;
11. Thompson 68-AMV Multi-Dart;
12. Thompson 68- ABL Multi-Dart;
13. MK 77 MOD 0 Gas Generators;
14. Mk 216 MOD 2 RF Distraction Charges.

The majority of these programs were 2.75-inch Rocket warheads and other small ordnance devices that required a high degree of impact precision and unobscured reaction monitoring.

### 4.2 SAMPLE TEST RESULTS

#### 4.2.1 <u>Test Results from MK 216 MOD 2 RF Distraction Charge Testing</u>

These tests were conducted at DRI's facility in Denver, Colorado in September, 1994. This project was the last official test program conducted using the precision delivery system in Colorado.

**Table 2. MK 216 MOD 2 Fragment Impact Test Data[11]**

| | FRAGMENT VELOCITY (ft/s) | | PEAK PRESSURE (psi) | |
|---|---|---|---|---|
| **TEST NUMBER** | **GUN 1** | **GUN 2** | **GAUGE 1** | **GAUGE 2** |
| FI-01 | 8298 | 8363 | 4.50 | 4.30 |
| FI-02 | 8316 | 8333 | 3.80 | 3.40 |

In Table 2, the peak pressure data refers to the muzzle blast pressure measured at the target area using the required pressure gauge location and orientation. No test article reaction greater than Type IV was observed in either test. At the time of these tests, the length of the 40-mm barrels was approximately 12-foot (3.66 m). Target to muzzle standoff was approximately 35.0-feet (10.7 m). Stripper plate to muzzle distance was approximately 8.0-feet (2.4 m). Velocities of the fragments were recorded approximately 11.25-feet (3.43 m) in front of the test article. A schematic of the test layout is shown in Figure 4 below.

### 4.2.2 Muzzle Blast Measurements

Muzzle blast measurements were taken using the blast gauges installed for the test for each gun, and for both guns fired simultaneously. Those data are summarized in Table 3 (values are approximate).

**Table 3. Muzzle Blast Calibration Measurements from MK 216 MOD[13]**

| | SINGLE GUNS (psi) | | DUAL GUNS (psi) |
|---|---|---|---|
| GAUGE NUMBER | GUN 1 | GUN 2 | |
| 1 | 2.80 | 2.50 | 2.90 |
| 2 | 2.25 | 3.10 | 2.80 |

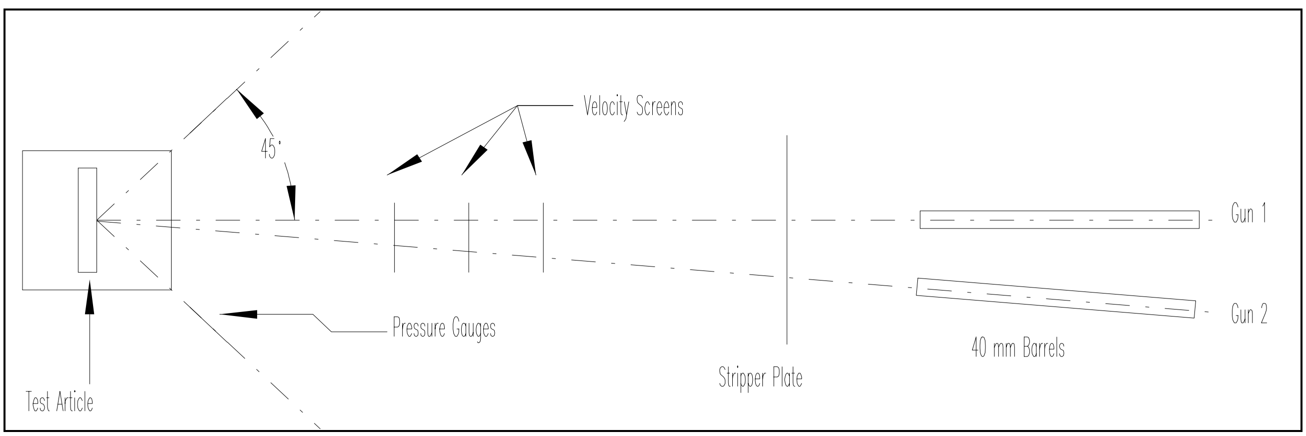


**Figure 4. MK 216 MOD 2 Fragment Impact Test Layout[12]**

## 4.3 TRANSFER TO NTS CAMDEN FACILITY

### 4.3.1 Performance Problems

In April of 1996, the DRI Precision Fragment Impact System was transferred to National Technical System's National Ordnance, Munitions and Environmental Test Center (NOMETC) in Camden, Arkansas as part of DRI's establishment of testing capability in Arkansas. Prior to this transfer, the 40-mm test barrels were reworked; approximately 4.0-inches (10.2 cm) were cut from the breech end of each barrel and the barrels re-threaded. This practice, utilized several times previously, restored the original internal dimensions of the barrels bringing the breech section diameter into tolerance with the forward sections of the barrels.

When the original shortened barrels were test fired at Camden using an identical powder load as fired at DRI's Denver range the velocity decreased from approximately 8300 ft/s (2530 m/s) to approximately 7400 ft/s (2256 m/s). When faster powders were introduced in an attempt to reproduce previous performance, velocities increased to 7900 ft/s (2408 m/s) but peak breech pressures were measured in excess of 120.0 kpsi (827 Mpa).

These firings did not yield the required MIL-STD-2105B velocity but did point out the lack of ballistic efficiency with respect to velocity versus in-bore pressure. Initial analysis of the problem indicated a significant change in thermochemical and aerodynamic performance between the Denver and Camden locations. These changes were attributed primarily to atmospheric and altitude effects (e.g. relative humidity, air density and associated drag).

### 4.3.2 Performance Analysis

In an attempt to explain the performance differences between Denver and Camden, DRI invited the Army Research Laboratory (ARL) to assist in their evaluation of the problem. ARL subsequently recommended a number of modifications to the DRI system that would improve performance and maximize the system's hardware life. ARL's primary recommendation was to reduce the mass of the launch package (sabot plus obtuator); reasoning that this relatively simple modification would result in the greatest improvement in velocity. By varying launch package mass while maintaining a relatively constant chamber pressure of 88.5 kpsi (610 MPa), ARL calculated that modest velocity increases were possible through increases in the weight of the main propellant charge.

These charge weight increments were calculated at 4 to 5 grams assuming a 20% decrease in overall launch package mass. ARL's report noted that a 10% reduction of mass in each component of the launch package could result in a 100 ft/s (30.4 m/s) to over 600 ft/s (182.2 m/s) for a 50% reduction.[14] ARL's conclusion, shared by DRI, was that a maximum 20% reduction in the overall launch package mass was risky but acceptable.

ARL also conducted an analysis of the aerodynamic problem using the projectile ballistic analysis tool "PRODAS", sold by Arrow-Tech Associates, Inc. The PRODAS tool, as stated in the ARL report is capable of *"…calculating mass and inertia properties, aerodynamic coefficients, flight stability parameters, and trajectories."*[15] ARL used the PRODAS tool to calculate the cubical fragment's drag coefficient over the Mach number range of interest, finding it nearly constant at a value of approximately 1.9. ARL stated that this value is consistent with drag coefficients found in other reference materials for rotating cubes flying face-on, as opposed to corner or edge-on. Parametric trajectories were then run varying initial altitude and air density inputs (i.e. Denver versus Camden). The results showed an overall velocity degradation of approximately 350 ft/s (106.6 m/s) at a range of 100-ft. (30.5 m).[16]

Interpretation of the ARL report and DRI's experience with varied length guns of the same design led to the conclusion that shortened barrels, in conjunction with the unanticipated effect of overall atmospheric conditions were responsible for the loss of ballistic efficiency and velocity degradation at the Camden facility.

## 4.4 RE-ENGINEERING

### 4.4.1 Design and Fabrication

It was determined that significant changes to the overall design of the barrels were required to return the system to its previous capabilities. These changes resulted in the order of brand-new 40 mm rifled bore barrels. The primary system design changes were reducing the launch package mass; increasing the length of the barrels to 15.0-feet (4.57 m); and using a slower burn rate propellant (enabling a higher loading density). These changes provided additional acceleration time in-bore for more efficient utilization of modest changes in charge weights and overall lower breech pressures.

The ARL report predicted an increase in velocity of approximately 246 ft/s (74.9 m/s) using the longer barrel design and the other modifications. The external diameter of the barrel was increased from 3.0 to 4.0-inches (7.62-10.16 cm) to strengthen the barrel against the peak pressures, approximately 85.0 kpsi (586 Mpa), needed to achieve the desired 8300 ft/s (2530 m/s) muzzle velocity in the Camden environment.

In 1997, new 15-foot (4.57 m) long by 4.0-inch (10.16 cm) diameter 40 mm rifled test barrels were manufactured to DRI specification by Ares, Inc. of Port Clinton, Ohio and shipped to the NOMETC facility. These barrels arrived in Camden, Arkansas in late August and were installed and qualified for MIL-STD-2105B testing requirements (Figure 5).

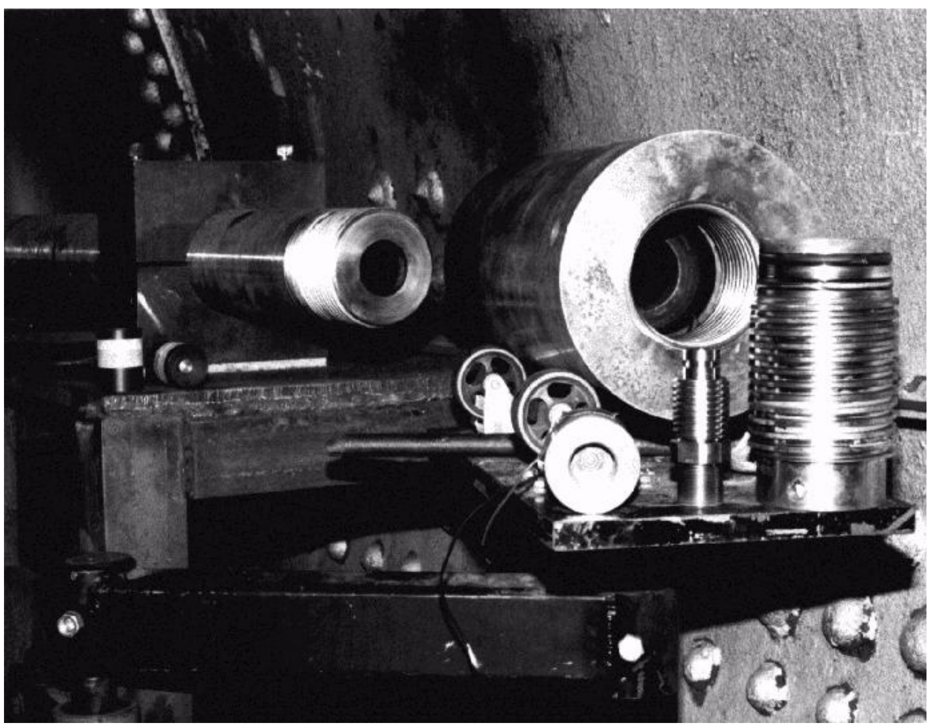

**Figure 5. New 40mm Barrel, Breech Block, Inserts and Launch Packages**

## 4.5 VELOCITY QUALIFICATION TESTING

Test firings of the new test barrels began in early September 1997, and nine qualifying shots for velocity and in-bore pressure were conducted (six and four firings in Guns 1 and 2 respectively). These firings were conducted to break-in the barrels and re-establish charge to velocity curves for each barrel. Initial propellant charge weights were developed by DRI from the data reported by ARL and from use of the IBHVG2 interior ballistics code. The first firings were expected to produce velocities in the 6000 - 7000 ft/s (1829 - 2134 m/s) range with peak in-bore pressures less than 60,000 psi (414 MPa). Progressive increases in the main charge weight produced higher pressures and velocities, as seen in the data presented in Table 4. Pressure values refer to the in-bore peak pressure measured at the main charge cavity using a piezo-electric transducer. Final pressure and velocity results closely matched ARL and DRI predictions.

ARL's recommended launch package optimization, an overall mass reduction of 20%, was implemented in Test 4 of Gun 1. The same propellant charge from Test 3 was used for Test 4 and resulted in a higher velocity and acceptable pressure increase. Subsequently, all of the remaining tests were fired utilized the reduced mass launch package. The shaded areas in Table 4 indicate the use of the reduced mass launch package.

These tests resulted in an impact pattern no larger than 2.0-inches (5.08 cm) in diameter, replicating the shorter test barrel's precision. The same overall range configuration, shown in Figure 6, was duplicated for these tests. Convergence of shot-lines occurred at approximately 41.0-feet (12.5 m) instead of 35.0-feet (10.7 m) due to the increased length of the barrels and unchanged traversal capacity of the barrel mounts.

**Table 4. Summary Record of Velocity Qualification Tests -- September 1997**

| | GUN 1 | | GUN 2 | |
|---|---|---|---|---|
| **TEST NO.** | **Velocity (ft/s)** | **Pressure (psi)** | **Velocity (ft/s)** | **Pressure (psi)** |
| 1 | 6580 | 39,806 | 6279 | 40,684 |
| 2 | 7767 | 77,045 | 7229 | 77,045 |
| 3 | 7900 | 91,032 | 7973 | 96,355 |
| 4 | 8156 | 94,661 | 8225 | 100,968 |
| 5 | 8320 | 108,194 | | |

## 4.6 FRAGMENT IMPACT TEST EXPERIENCE

### 4.6.1 First Alternate Fragment Impact Test

A set of first alternate Fragment Impact tests using the single cylindrical fragment at 6000 ft/s (1829 m/s) were completed after the initial velocity qualification firings with Gun 1. The test articles were new Mk 66 MOD 4 CRADA Rocket Motors developed for use on 2.75-inch rocket munitions. The 40-mm precision system easily achieved both impact accuracy and velocity criteria during these tests. Two tests were conducted using this technique.

**Figure 6. Qualification Range Layout at NTS Camden**

4.6.2 Preferred Fragment Impact Test

A successful set of dual fragment impact tests using the 40 mm gun system were completed against the Mk 244 Mod 0, 20 mm Armor-Piercing Discarding Sabot (APDS) Enhanced Lethality Cartridge in July '98. The live 20 mm rounds were packaged in standard M548 metal ammunition containers, with targeting impacts on the base (primer) end, and the nose (projectile) end. The rounds were stored in the M548 containers with Mk 7 links according to Mk 149 packaging requirements. For these tests, a single container containing 100 rounds was fired upon with the largest side of the container facing the launch barrels (Figure 7). The container side selected for impact was determined based upon the desired targeting of either the round's base or projectile end.

**Figure 7. Container Impact Location and Orientation**

Table 5 lists the firing data from each test, demonstrating the capability of the system to consistently deliver two cubical fragments within the specification velocity range of 8300 ± 300 ft/s. Launch package weights, including the cubical fragments were 120 and 121 grams (1865 and 1849 grains) for Shot 1, 122 and 120 grams (1846 and1880 grains) for Shot 2.

**Table 5. Preferred Method Fragment Impact Test -- Mk 244 Mod 0 20 mm APDS**

| | | GUN 1 | | GUN 2 | |
|---|---|---|---|---|---|
| **Test No.** | **Target Impact** | **Velocity 1 (ft/s)** | **Velocity 2 (ft/s)** | **Velocity 1 (ft/s)** | **Velocity 2 (ft/s)** |
| 1 | Nose | 8226 | NR | 8162 | 8203 |
| 2 | Base | 8050 | NR | 8380 | 8416 |

Figures 8 and 9 show the post-impact damage to the containers and the rounds within. Figure 10 presents an overview of the test set-up, showing the protected gun system to the left, the sabot stripper plate, velocity measurement stand, and the target stand with M548 container in place.

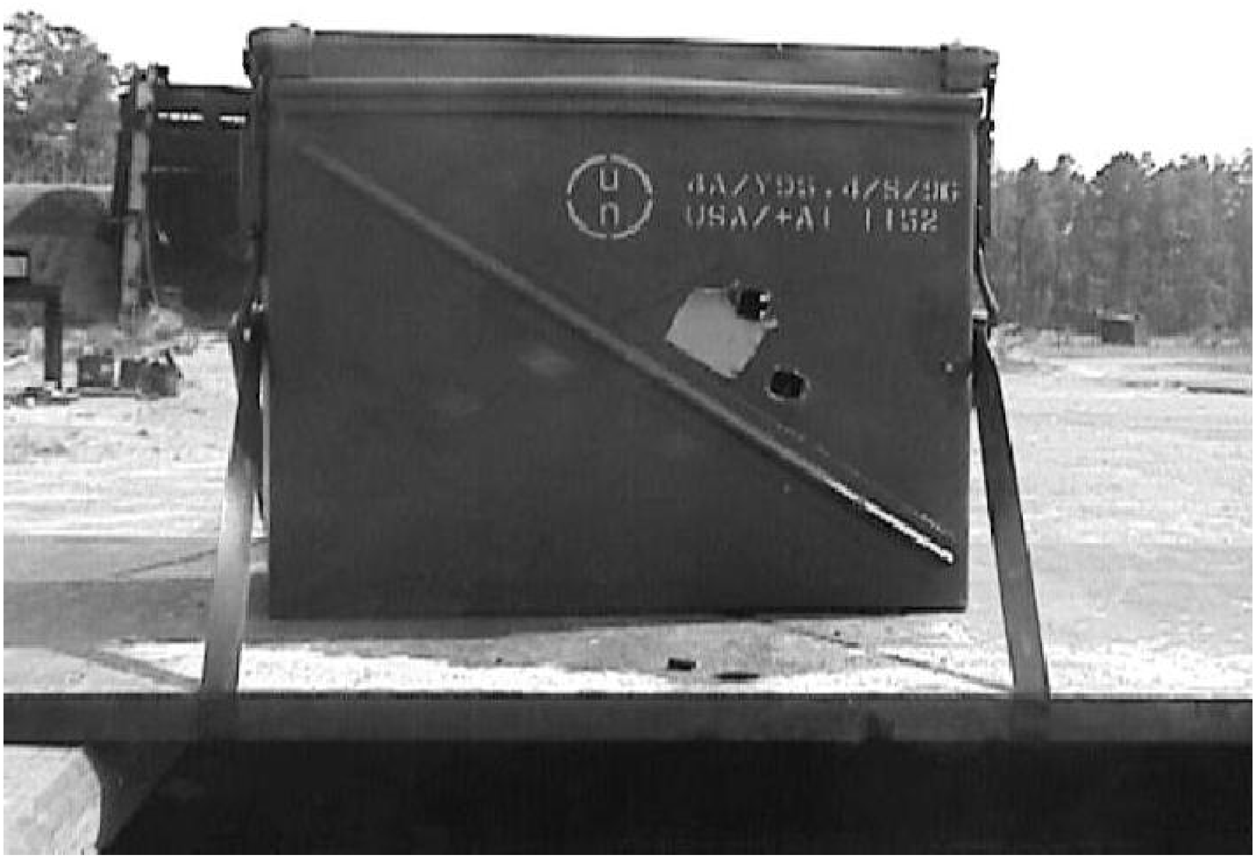

**Figure 8. Post-Test Results -- Impact Face**

**Figure 9.  Post-Test Results -- Nose Impact**

**Figure 10.  Mk 244 Mod 0 Fragment Impact Test Configuration**

## 5.0 CONCLUSION

A highly efficient, precision test system and methodology for conducting the preferred option of the MIL-STD-2105B Fragment Impact test has been developed, qualified and proven successful. The powder gun based, 40 mm ballistic launch system, utilizing twin 15-foot long test barrels, offers a unique precision alternative to the test influencing explosive launchers.

Use of the precision delivery system ensures accurate targeting and fragment orientation at impact. The 40-mm gun system offers lower launch device pressure contributions and greatly enhanced viewing of the test when compared to the traditional FRAGMAT launcher. All of these advantages combine to increase the overall precision, consistency, and targeting options for the MIL-STD-2105B Fragment Impact test's preferred method, generating higher confidence and acceptance of the results.

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